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HYDROLOGIC DESIGN OF FARM PONDS AND RATES OF RUNOFF FOR DESIGN OF CONSERVATION STRUCTURES IN THE NORTH APPALACHIAN REGION

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FOREWORD

This publication is one of a series containing information for the hydrologic design of farm ponds and of other conservation structures and practices in important agricultural areas where hydrologic studies have been made by the Soil Conservation Service. The information and procedures contained in this publication are based on runoff, rainfall, and other hydrologic data obtained from research projects of the Service at Coshocton and Zanesville, Ohio, conducted in cooperation with the Ohio Agricultural Experiment Station. United States Weather Bureau records of precipitation, published and unpublished records of stream flow of the United States Geological Survey, and available records from other sources are also utilized in the preparation of this technical publication.

Basic hydrologic data for the North Appalachian Region, particularly records of runoff from small watersheds, are still limited especially as to length of record. More definite information is needed on rates and amounts of seepage losses from reservoirs. Very little is known regarding the rate of sediment deposit in small reservoirs. Studies of runoff as well as of moisture movement into and through different soils and of land use must be continued over a period long enough to evaluate accurately the value of rates and amounts of runoff for various recurrence intervals under a variety of conditions. Field studies of evaporation from small reservoirs must be conducted to verify or modify the values used in this report. In view of the above, the information contained in this publication must be considered tentative and subject to revision. It is expected that such deficiencies in basic hydrologic data will be eliminated in time and that more reliable recommendations can be made.

The simplified instructions in this publication are made available for use in planning the general run of small farm ponds, the cost of which usually do not exceed $500. Certain basic data are included herein which can be used in complete hydrologic designs for costlier developments and in the design of smaller ponds in which only minor fluctuations in the depth of water can be permitted.

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SYNOPSIS

This report consists of three parts. Part I is for use in the hydrologic design of farm ponds. Part II gives rates of runoff for use in the design of conservation structures on agricultural areas up to 10,000 acres. Part III presents data on sedimentation. The areas of application are shown on figure 1.

The values and recommendations are based mainly on the analysis and interpretation of hydrologic records obtained on United States Soil Conservation Service research projects.* Because the hydrologic design of farm ponds and conservation structures involves estimates of future occurrences and because of the deficiency of long-term runoff records on small watersheds, the values presented in this report were made to be on the safe side. For this reason, no "factors of safety" need be applied to the recommendations.

Owing to the inadequacy of data available, complex and exact design procedures are not warranted. Simplification is stressed throughout. As longer records become available, the data presented herein can be refined and more exact and reliable recommendations made. Runoff totals for various sections of the region are given for the two kinds of soil discussed under "Sources of Data." For others, interpolation may be necessary.

No information is included on the structural design and hydraulic characteristics of grassed channels, terraces, spillways, and other structures used in the disposal of runoff. Such can be obtained from published reports of the Soil Conservation Service, Regional Engineers Handbooks, and from other publications dealing with these subjects.

Seepage losses may be critical in some areas. The geology of the site should be thoroughly investigated. No pond will prove satisfactory if seepage losses are excessive. Some ponds in this area are known to lose 5 or 6 feet of water in 1 or 2 days by seepage alone. Each site is a problem of its own and as such, warrants its own specific investigation.

In pond designs, three important features are to be kept in mind: (1) Provide sufficient drainage area to furnish adequate quantities of runoff water in the pond during critical drought periods; (2) keep the drainage area small so as to minimize reservoir silting and to minimize emergency spillway requirements; and (3) keep at least 50 percent of the drainage area in permanent vegetal cover such as grass or woods so as to minimize reservoir silting resulting from watershed erosion. The recommendations contained in this report are made in light of these criteria. The design of diversion ditches, terraces, waterways, spillways for gully-control structures, soil-saving dams, and the like usually have less flexibility in the selection of size of drainage area than those for pond sites. For such, the hydrologic design is merely the determination of the flood peak value for a selected probable recurrence interval (Part II).

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*Acknowledgment is made to valuable suggestions by Lewis A. Jones, Chief, and W. D. Potter, Soil Conservationist, and to others in Soil Conservation Research, U. S. Soil Conservation Service.

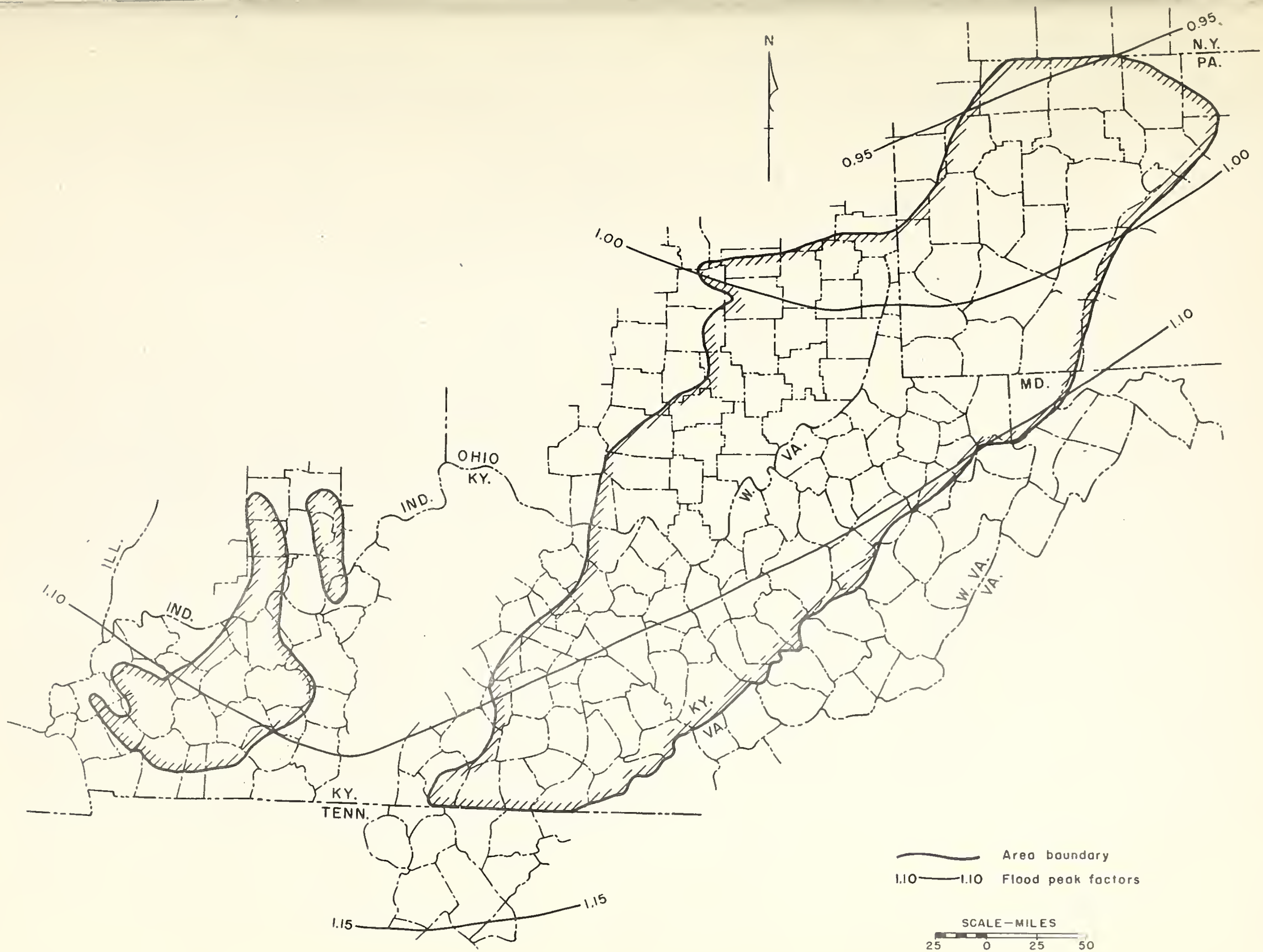

Figure I.– Approximate area of application, North Appalachian Region.

Soil Conservation Service, Washington, D.C., 1947

SOURCES OF DATA

Runoff

Watershed data (1935-42) from the United States Soil Conservation Service, Northwest Appalachian Conservation Experiment Station, Zanesville, Ohio, H. L. Borst, project supervisor, served as the basis of the recommendations for areas where soils underlain by clay or shale predominate. Watershed data (1939-46) from the United States Soil Conservation Service, North Appalachian Experimental Watershed, Coshocton, Ohio, served as the basis for areas of the permeable Muskingum silt loam. United States Geological Survey records from the 1,050-acre Holm Creek watershed near New Philadelphia, Ohio (1937-46), Hocking River at Athens, Ohio, and Shenango River at Sharon, Pa., were also used. The three watersheds at Zanesville were all less than 4 acres in area. Watersheds at Coshocton ranged from 2 to 4,580 acres in size.

Precipitation

United States Weather Bureau records for 50 years formed the basis of precipitation-frequency data. These data along with the Soil Conservation Research data of rainfall-runoff relationships formed the basis of 50-year synthesized runoff records.

Evaporation

Evaporation records at the Coshocton research station along with Adolph Meyer's long-term data in "Evaporation from Lakes and Reservoirs," by the Minnesota Resources Commission, were used.

The runoff and evaporation records are far too meager to permit a complete analysis on which to base final recommendations for design. However, in view of the urgent need for hydrologic data in connection with the rapidly expanding conservation programs, it is deemed advisable to make available the best estimates possible from the records obtained thus far. The recommendations contained in this publication must be considered tentative, and subject to revision. In the present status of the science of hydrology, rigorous proofs are seldom possible. Some of the recommendations must, therefore, be based on the judgment of the authors guided by experience and knowledge of hydrologic phenomena. For this reason, and because this report is intended primarily as a guide in design of conservation structures and practices, no attempt is made to discuss the procedures followed in arriving at suggested rates of runoff and other data. The brief discussion is devoted mainly to the methods to be followed in utilizing the results of the analysis in the hydrologic design and planning of farm ponds and of other conservation structures and practices.

PART I. HYDROLOGIC DESIGN OF FARM PONDS

General Considerations

"A pond on every farm" is rapidly becoming a slogan and aim of many in the North Appalachian Region. Some dams have been built without consideration of geologic and hydrologic factors. Consequently, there have been a number of failures.

In the farming of specialty crops, irrigation is becoming a "must." "Grassland agriculture" in the raising of beef and dairy cattle in this region has greatly increased the interest in and need for ponds for stock water. Several ponds located at different points in large orchards are proving to be advantageous for spraying purposes. Also, the ponds are furnishing water for fire protection, raising fish for food, and providing for wildlife and recreation.

Seepage from the pond and inadequate spillways are two of the most serious causes of pond failures in the region. The proximity of crevaced limestone or other permeable rock strata to the bed of the pond should be thoroughly investigated before the site is finally determined.

Much of the soil in the North Appalachian Region is well drained. For such, small areas in good grass or woods do not provide sufficient quantities of surface runoff water to maintain ponds. Most of the rainfall goes into the ground. As the size of the drainage area increases, seeps and springs usually appear down the slope. Here, a part of the water taken up by the soil on the small upland areas reappears as surface flow. On the heavier, less well-drained soil, these seep spots appear even on the small drainage areas. The quantity of dependable supply of runoff water on the small watersheds located on the heavier soils is, therefore, considerably larger than that on the small watersheds on the light, well-drained soils. On the large watersheds where the return seep flow occurs in both the light and heavy soils, there is likely to be little or no difference in the quantity of dependable flow into the pond.

Although the various factors involved in the study of the hydrology of farm ponds are complex, the design procedure presented herein has been simplified to a large extent.

Definition of a Dependable Water Supply

One of the primary considerations in a farm pond designed to furnish required amounts of usable water is the dependability of the water supply. Let us first consider the time required to fill the pond after construction. If the pond reservoir is large and the drainage area above the dam is small, several years may lapse before there is sufficient runoff to fill the pond. For ponds in this region having a small water-use demand, the filling time is a major factor in determining the minimum required drainage area above the pond site. It appears desirable that sufficient drainage area be provided so that the ponds be filled in 18 months after completion. This would include two growing seasons. Runoff volumes that can be depended on 75 percent of the time are used in this consideration. Over half the time the pond will fill in a period of less than 18 months.

Once the pond is full, the success or failure of the water supply in the pond will depend on the use requirements, seepage losses, evaporation, available runoff from the watershed above the pond, rainfall on the pond, and maximum depth the water in the pond can be drawn down before a failure occurs. In balancing these factors to determine the size of drainage area required to supply runoff water to meet the demands, it appeared desirable to accept on the average not more than one failure in 25 years. In other words, rainfall, runoff, and evaporation data were used to satisfy 96 percent of the time.

From a study of the hydrologic factors for critical drought periods, it was concluded that provision should be made for an 18-month period extending over two growing seasons. It was found that critical drought periods of shorter duration than 18 months as well as those of longer duration would require less drainage area than that for the 18-month period.

The determination of the minimum required drainage area will be for many sites simply a check to see that the available drainage area is adequate. If the area is too small, possibly there will be satisfactory sites farther downstream. Perhaps a pond of smaller depth will suffice. There will be many farms where only one good dam site is available. It may not be possible to select a dam farther downstream in order to get greater drainage area. If the drainage area above the only good dam site is found to be too small to meet the demands, one or both of the following steps may be taken:

a. Construct diversion terraces to drain runoff water into the watershed from outside areas -- thus increasing the size of the drainage area by the required amount. If this is considered, the legality of such a diversion should be investigated.

b. Increase the depth of the pond by raising the spillway elevation. This will, in many cases, increase the pond area materially at spillway elevation. If this happens, the increase in pond depth may not help much. It may be necessary, therefore, to build dikes to prevent the pond from spreading over too great an area.

Step "a" will meet the needs both for filling the pond and maintaining an adequate supply. Step "b" will eliminate the deficiency only for maintaining an adequate supply. This step would require either a greater drainage area or a longer time to fill the pond.

Definitions of Symbols Used in Tables and Text

U (inches) = Amount of water required for livestock, irrigation, etc., during the period.

A (acres) = Size of watershed area above pond.

r (inches) = Runoff from the drainage area during the period.

a (acres) = Mean surface area of pond = 0.4 times surface area at spillway elevation. May also be

$$\frac{\text{Reservoir capacity (in acre-inches)}}{\text{Depth (d)}}$$, or determined from figure 2.

P (inches) = Precipitation depth falling on the pond during the period.

E (inches) = Evaporation depth from the pond during the period.

D (inches) = Maximum depth of pond below spillway elevation.

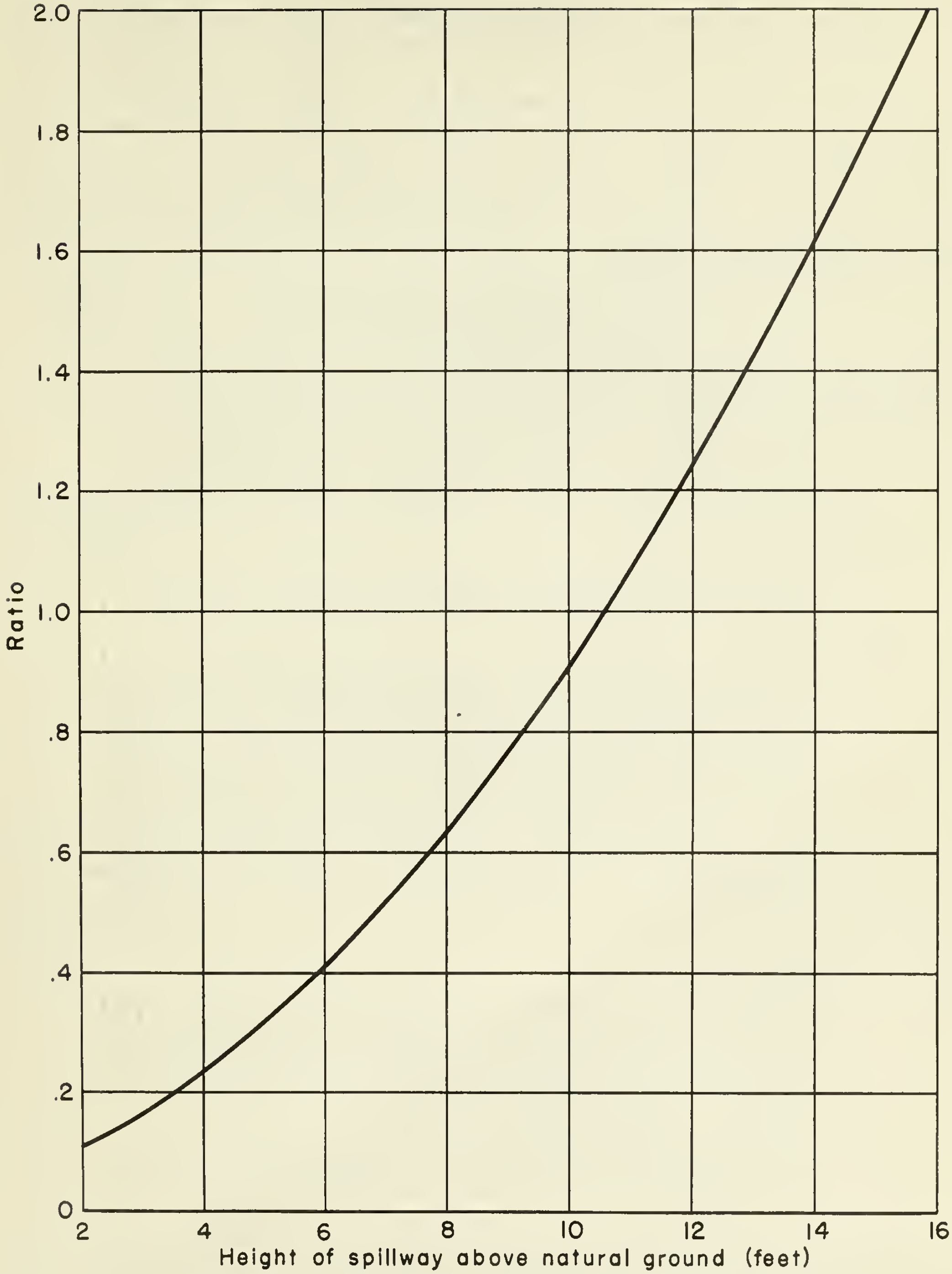

Figure 2.– Ratio of "Mean surface area" to Surface Area at 6 feet above Natural Ground for ponds with various Heights of Spillway.*

* From Figure 4: "Area relationships that simplify the hydrologic design of small farm ponds", by W. D. Potter and D. B. Krimgold— Agricultural Engineering, Vol. 6, P. 269.

It is well to emphasize the meaning of the expectancies mentioned in the foregoing discussion. When we say that a given amount of water for a critical period can be expected to be equaled or exceeded 96 percent of the time, on an annual basis, or, in other words, 24 out of 25 years, we do not mean that 24 years will necessarily elapse before a smaller amount will occur. This may not happen at all in 25 years, or it may happen more than once and at any time during a 25-year period. We mean that over a long period, say 100 years, lesser amounts will occur on the average not more than four times. The same reasoning applies to 75, 80, or 90 percent of the time. It is important that this concept be clearly understood by both technicians and farm cooperators in the districts when technical assistance in the design of farm ponds is rendered.

Hydrologic Design Procedure

To determine the size of drainage area required, proceed as follows:

Step 1. For selected pond site, determine surface area and depth of pond at elevation of principal spillway or at 6-foot elevation if figure 2 is used. Check geology for possible seepage losses.

Step 2. Determine for the watershed the predominant kind of soil and classify it as to drainage.

Step 3. Enter table 1(a, b, c, or d, depending on location of job) with the pond depth and mean pond area (0.4 of pond surface area at spillway elevation) and the soil drainage; select the size of watershed drainage area required to fill the pond. The mean pond area can also be obtained from a survey of the pond at 6 feet above the natural ground and a coefficient depending on the height of the spillway. (See figure 2.)

Example for Steps 1 to 3

Given a pond site having a surface area at depth of 6 feet of 2.35 acres and spillway at depth of 7 feet. From figure 2, mean pond area = 2.35 x 0.51 = 1.2 acres. Watershed in slowly permeable Muskingum soil, springs and seeps in drainage area above site.

Drainage area from table 1(a) required to fill pond = 14 acres (column 5). Available use = 102 acre-inches.

Drainage areas determined from table 1(a, b, c, and d) will provide without failure 96 percent of time a certain amount of water for use in an 18-month period. For greater use demands or where seepage losses occur, additional drainage area will be required.

TABLE 1(a).--Drainage area required to fill pond with water in 18 months and corresponding quantities of water available for use in parts of--

OHIO

1	2	3	4	5	6	7	8
Soil profile drainage	Mean surface area of pond (a)	Minimum drainage area and volume of water available for 18-month use during critical drought periods for ponds having depths of--					
		D = 60 inches		D = 84 inches		D = 120 inches	
		A	Use (Ua)	A	Use (Ua)	A	Use (Ua)
	Acres	Acres	Acre-inches	Acres	Acre-inches	Acres	Acre-inches
Well-drained areas having no seeps or springs	0.1	15	6	19	10	26	15
	.2	28	12	38	20	52	30
	.4	55	24	75	39	105	60
	.8	110	49	150	78	210	120
	1.2	165	73	225	117	315	180
Slowly permeable areas and large well-drained areas having seeps and springs	.2	5	20	5	24	5	32
	.4	5	25	5	35	5	55
	.8	7	42	10	70	14	110
	1.2	10	61	14	102	20	162
	1.6	14	84	19	136	26	214
	2.0	17	104	24	172	33	268

TABLE 1(b).--Drainage area required to fill pond with water in 18 months and corresponding quantities of water available for use in parts of--

PENNSYLVANIA AND WEST VIRGINIA PANHANDLE

1	2	3	4	5	6	7	8
Soil profile drainage	Mean surface area of pond (a)	Minimum drainage area and volume of water available for 18-month use during critical drought periods for ponds having depths of--					
		D = 60 inches		D = 84 inches		D = 120 inches	
		A	Use (Ua)	A	Use (Ua)	A	Use (Ua)
	Acres	Acres	Acre-inches	Acres	Acre-inches	Acres	Acre-inches
Well-drained areas having no seeps or springs	0.1	12	6	16	9	23	14
	.2	24	12	33	18	46	29
	.4	47	23	65	37	92	58
	.8	95	46	130	74	184	115
	1.2	140	70	195	111	276	173
Slowly permeable areas and large well-drained areas having seeps and springs	.2	5	28	5	33	5	40
	.4	5	34	5	44	6	62
	.8	6	50	8	78	12	123
	1.2	9	76	12	118	17	185
	1.6	12	100	16	157	23	247
	2.0	15	126	20	196	29	308

TABLE 1(c).--Drainage area required to fill pond with water in 18 months and corresponding quantities of water available for use in parts of--

WEST VIRGINIA AND EASTERN KENTUCKY

1	2	3	4	5	6	7	8
Soil profile drainage	Mean surface area of pond (a)	Minimum drainage area and volume of water available for 18-month use during critical drought periods for ponds having depths of--					
		D = 60 inches		D = 84 inches		D = 120 inches	
		A	Use (Ua)	A	Use (Ua)	A	Use (Ua)
	Acres	Acres	Acre-inches	Acres	Acre-inches	Acres	Acre-inches
Well-drained areas having no seeps or springs	0.1	8	6	11	9	16	14
	.2	15	11	22	18	31	29
	.4	30	22	43	36	63	57
	.8	60	45	86	73	130	115
	1.2	90	67	130	109	190	171
Slowly permeable areas and large well-drained areas having seeps and springs	.2	5	37	5	41	5	49
	.4	5	43	5	53	5	67
	.8	5	57	5	76	7	116
	1.2	6	76	8	117	11	178
	1.6	7	95	10	150	15	240
	2.0	9	120	12	190	18	300

TABLE 1(d).--Drainage area required to fill pond with water in 18 months and corresponding quantities of water available for use in parts of --

WESTERN KENTUCKY AND INDIANA

1	2	3	4	5	6	7	8
Soil profile drainage	Mean surface area of pond (a)	Minimum drainage area and volume of water available for 18-month use during critical drought periods for ponds having depths of--					
		D = 60 inches		D = 84 inches		D = 120 inches	
		A	Use (Ua)	A	Use (Ua)	A	Use (Ua)
	Acres	Acres	Acre-inches	Acres	Acre-inches	Acres	Acre-inches
Well-drained areas having no seeps or springs	0.1	10	5	14	8	19	13
	.2	20	10	27	16	38	26
	.4	40	19	54	32	75	52
	.8	80	38	108	65	150	105
	1.2	120	57	162	97	225	157
Slowly permeable areas and large well-drained areas having seeps and springs	.2	5	29	5	34	5	41
	.4	5	34	5	43	5	58
	.8	5	42	7	72	10	115
	1.2	8	66	9	100	14	170
	1.6	10	85	14	140	19	225
	2.0	12	108	17	180	23	280

Step 4. Estimate the water-seepage loss plus water-use demands for the pond for an 18-month period that includes two growing seasons. If this total exceeds that given in table 1, the size of the drainage area determined in step 3 will have to be increased. If this amount is less than that given in the table, no further steps are necessary. It is believed that there will be only a few cases where additional area is required.

Step 5. For excessive use demands, determine the additional drainage area required using the hydrologic data for that locality given in table 2 for 96 percent of time expectancy.

Example for Steps 4 and 5

Use demand = 124 acre-inches for 18-month period covering two consecutive growing seasons. For 14 acres of watershed the water available for use is 102 acre-inches. Additional drainage area required to make up the difference of 124 - 102 = 22 acre-inches.

Using data in table 2 for Ohio:

$$A' = \frac{Ua}{r} = \frac{22}{2.8} = 7.9 \text{ acres}$$

Total drainage area = 14 + 7.9 = 21.9 acres

Note: If the use demand for 18 months had been 102 acre-inches or less the watershed area of 14 acres would have been adequate--no additional drainage area needed.

PART II. RATES OF RUNOFF FOR USE IN DESIGN OF SPILLWAYS AND OTHER CONSERVATION STRUCTURES

In the North Appalachian Region where much of the area is in woods or grass and where the physiographic and hydraulic characteristics of watersheds do not differ greatly, one set of flood-design data can be used (table 3). In view of the limited amount of data available, refinements are not warranted. Profile drainage differences in the region are of less importance in causing flood peaks than they are in causing differences in runoff totals from watersheds. One set of values (table 3) can, therefore, be used for the whole region.

In this region, rainfall intensities increase from the northern to the southern counties. In order to provide for corresponding variations in runoff, coefficients (runoff factors shown on map, fig. 1) depending on the location of the watershed

TABLE 2.--Rainfall, runoff, and evaporation data for determination of size of drainage area requirements for ponds.

1	2	3	4	5	6	7	8	9
Location	Rainfall for 18-month period (P)		Runoff for 18-month period (r)				Evaporation (E)	
			Well-drained areas having no seeps or springs		Slowly permeable areas and large well-drained areas having seeps and springs			
	75%	96%	75%1/	96%2/	75%	96%	75%	96%
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches
Ohio	54	42	0.48	0.24	7.6	2.8	60	74
Pennsylvania) West Virginia Panhandle)	57	46	.54	.24	8.6	4.5	61	77
West Virginia) Eastern Kentucky)	64	50	.75	.31	13.0	6.0	61	77
Western Kentucky) Indiana)	62	46	.68	.26	11.0	5.0	70	84

1/Quantities dependable for 75% of time. Used in determination of required drainage area for filling pond.

2/Quantities dependable for 96% of time. Used in determination of water available for use and of required drainage area for maintaining adequate supply of water in pond in critical dry periods.

TABLE 3.--Flood-peak runoff rates for watersheds in the North Appalachian Region having good permanent vegetal cover[1/] (50 to 75 percent or more in grass and woods) (SEE FIG. 1 for LOCATION-FACTORS MODIFYING THESE DATA)

Watershed area (acres)	Flood peak (cubic feet per second per acre)				
	2-year	5-year	10-year	25-year	50-year
5	0.6	1.3	2.3	4.0	7.6
10	.6	1.2	2.2	3.9	7.3
20	.6	1.2	2.1	3.8	7.0
50	.6	1.2	2.0	3.7	6.4
100	.6	1.1	1.7	3.1	5.2
200	.47	.8	1.3	2.2	3.6
500	.33	.58	.88	1.5	2.3
1,000	.26	.43	.64	1.04	1.6
2,000	.20	.33	.47	.73	1.1
3,000	.16	.26	.38	.58	.87
4,000	.14	.23	.33	.50	.73
6,000	.13	.20	.28	.41	.60
10,000	.10	.15	.22	.31	.45

[1/] Where entire watershed is cultivated in a 3- or 4-year rotation (1 or 2 years in grass) multiply peak values shown in this table by 1.7. Where entire watershed is in woods or good grass cover, multiply values by 0.6.

should be applied to values in table 3.

> For example: For the 21.9-acre watershed, the 50-year peak runoff rate = 7.0 x 21.9 = 153 cfs. If this watershed were in Wirt County, W. Va., the runoff factor would be 1.08 and the adjusted flood peak would be 1.08 x 153 = 165 cfs.

The values given in this table are for structures to be designed to handle floods safely up to the 2-, 5-, 10-, 25-, and 50-year recurrences. Values for 2- and 5-year recurrences are given for use in drainage works where such are needed for designs. When the cost of replacing the structure or the damage that would result from its failure is excessive, floods of 100 or more years recurrence should be considered. In that event, special analysis should be made.

It is also likely that large structures may be so costly so as to warrant the consideration of reduction of flood peak due to reservoir storage. Values in table 3 are simply runoff from the watershed. For large reservoirs these peaks may be reduced considerably before they pass through the spillway. Procedure for such determinations is a part of the Regional Engineering Handbook.

PART III. POND SEDIMENTATION

Drainage areas should be as small as possible and, whenever practical, should be kept mostly in woods or good pasture or meadow grasses so as to keep to a minimum the amount of eroded material, or sediment, entering the pond. Erosion and, therefore, sedimentation will be negligible when at least 90 percent of the area is in grass or woods. If stream-bank or gully erosion occurs in the area, the rate of sedimentation will be greater than that given in table 4. If such erosion is prevalent it should be stopped.

Sedimentation is a problem when much of the drainage area is cultivated. Records of erosion from both the Zanesville and Coshocton Experiment Stations show that even with a good crop rotation in the entire drainage area above a pond sedimentation may be serious. These data, along with the land-slope effect, are given in table 4.

TABLE 4.--Annual rates of pond sedimentation (acre-feet) per acre of drainage area.

Land use	Soil drainage	Land slope (percent)			
		6	9	12	18
Small drainage areas in 3-year rotation (corn-wheat-meadow)	Well drained	0.002	0.004	0.006	0.011
	Slowly permeable	.003	.006	.010	.018
Small drainage areas in 4-year rotation	Well drained	.001	.003	.004	.007
	Slowly permeable	.003	.005	.008	.015
Large mixed-cover areas (woods 50%, grass 20%, and rotation land 30%)	Well drained	.0007	.001	.002	.004
	Slowly permeable	.001	.002	.003	.006
Large areas in woods or grass	Either type	Negligible	Negligible	Negligible	Negligible

Example: If the 21.9-acre watershed (used in the example for Section 1) was 50 percent in meadow, 25 percent in corn, and 25 percent in wheat, all operating in a 4-year rotation of C-W-M-M, and the land slope averaged 12 percent, the annual sedimentation in the 8.4 acre-foot pond would be 21.9 x 0.008 = 0.175 acre-feet. In 10 years, more than one-fifth of the pond reservoir volume (1.75 acre-feet) would be lost. Instead of having a 7-foot depth, somewhat less than 5.6-foot depth would remain. During critical drought periods less water than originally planned would be available for use.

In table 4, sedimentation data are 70 percent of the actual soil loss values. This reduction is due to the fact that some of the eroded material is deposited in a delta at the entrance to the pond and some of the erosion passes over the spillway. Sixty pounds of dry eroded material were assumed to make up 1 cubic foot of deposit (soil and water).